REPORT OF AN INVESTIGATION OF CONDENSER PERFORMANCE IN THE ST. LOUIS WATER DEPARTMENT[1]

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About a year ago it was realized that the vacuums of our triple expansion pumping engines were not all that might be desired. We decided, therefore, to make a thorough study of our condensing apparatus, with a view of increasing the vacuum on all of our pumps. Our investigations were made on an engine at the Bissell's Point station. One was selected whose vacuum was particularly poor. The condenser on this engine is of the surface type with a two pass water travel through the tubes. The condenser is installed away from the main suction pipe but it is piped to the same. Water is shunted by means of a damper in the suction pipe of the pump to the condenser and discharged, after passing through the condenser, back into the suction pipe. This arrangement lends itself well to the purpose of varying the quantity of cooling water through the condenser.

The first possible fault to be investigated was the steam distribution throughout the length of the condenser. This was done because the engineer in charge of the plant felt sure that the condensor was clean. Temperature measurements along the shell did disclose hotter and colder parts of the condenser, indicating an uneven distribution of the steam through the condenser, but an attempt to correct this situation by rearranging the baffling made no appreciable change. Since we assumed the condenser was clean, the presence of air in the condenser was next investigated, proceeding as follows:

The necessary apparatus consists of a glass U-tube, half filled with mercury, at least 32 or more inches long, two low-reading thermometers, (reading up to 200°F. being ample) and a barometer.

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The U-tube is connected into the condenser near the air pump suction. One thermometer, inserted into a thermometer well at the steam entrance to the condenser, records the vacuum temperature. The other thermometer is inserted into a thermometer well at the bottom of the condenser near the air pump suction. The latter records the vapor temperature at this point, from which the vapor pressure may be obtained by reference to the steam tables. The barometer is hung preferably near the U-tube so that the temperature of the mercury in both the barometer and U-tube are the same, which will avoid the necessity of correcting the lengths of the mercury columns to the same temperature. The U-tube has the pressure of the atmosphere on one leg and the pressure in the condenser on the other leg, the difference in the height of the legs, therefore, being a measure of the difference between the atmospheric pressure and that in the condenser. The barometer has the pressure of the atmosphere on one side and a practically perfect vacuum on the other side of the mercury column, hence it measures the difference between the atmospheric pressure and that of a perfect vacuum. The difference between the barometer reading and that of the U-tube is then a measure of the pressure in the condenser above the perfect vacuum and is known as the absolute pressure.

It is usual to express the absolute pressure in the condenser in terms of a vacuum in inches of mercury below the atmospheric pressure, when the barometer is at 30 inches. The mean atmospheric pressure at sea level is 14.7 pounds per square inch, which corresponds to a height of 30 inches of mercury at 58.4°F. If the barometer and vacuum column are corrected to a temperature of 58.4°F., then the difference between the two will give the absolute pressure within the condenser in inches of mercury at 58.4°F. If this difference is subtracted from 30 inches, we have the number of inches of vacuum referred to 30 inches barometer. There are tables and charts available for making these corrections published by the leading condenser manufacturers.

The absolute pressure is thus obtained corrected to a 30-inch barometer. If no air were present in the condenser but only water vapor, this pressure would be equal to the vapor pressure in the condenser, corresponding to the temperature of the vapor, which is measured by the thermometer near the wet vacuum pump suction. If we look up the vapor pressure (in the steam tables for condenser work expressed in inches of mercury referred to a 30-inch barom-

eter), and find it to be lower than the absolute pressure, then the difference between the two is attributed to air and is, by Dalton's laws, a measure of the air pressure in the condenser in inches of mercury.

As stated before, the reading of the thermometer at the wet vacuum pump suction was taken to determine the vapor pressure, rather than the one in the steam entrance to the condenser, the former being at the bottom of the condenser where the air is present in greatest amounts, as will be shown later.

Having applied these principles to the condenser of the pump in question it was found that the air pressure was excessive. Good practice does not permit more than ½ inch of mercury. The air pump, which is of the type that handles both the air and water, as is common on large pumping engines, has a piston ring of 3-inch depth, made in two halves and is held out against the cylinder walls with flat springs. The cylinder was found to be sufficiently true to bore so that by setting out the ring the piston became practically water tight. When this was done the vacuum rose from 28 to 28½ inches. This happened in mid-winter when the circulating water in the condenser was coldest for the year. As the spring season progressed and the circulating water became warmer, the vacuum again dropped off, until at the end of May it was down to 26 inches with an air pressure of less than ½ inch. It was now decided, despite the information that the condenser was clean, that it must be dirty, for the temperature difference between the steam end thermometer or the vacuum temperature, and that of the out going circulating water was 42.9°F. The heat transfer was only 87 B. t.u. per square foot of condenser surface per hour, a very low figure. It was decided, therefore, to clean the condenser and, as anticipated, the condenser tubes were coated with a very heavy scale. After cleaning it the vacuum rose to 27.9 inches, with 0.45 inches of air and a heat transfer of 237 B.t.u. Later, in winter, when the circulating water was again cold, the vacuum rose to 29 inches.

Tabulating these values we have (see table 1).

Item 5 equals items 3–4. Item 6 equals 30 inches—item 5. Item 8 is taken from steam tables (referred to a 30-inch barometer) for pressure corresponding to item 7. Item 9 equals items 5–8. Item 11 is taken from steam tables (referred to a 30-inch barometer) for vacuum corresponding to item 10. For practical purposes, item 16 may be found by measurement of the quantity of circulating

water per hour, W pounds, noting its temperature rise and proceeding as follows: W $\times$ (Items 14–13) $\div$ (square feet of heating surface $\times$ items $10 - \frac{13 + 14}{2}$), or if the steam consumption per hour, S lbs., is known, item 16 may be found as follows: S $\times$ latent heat at temperature of item 10 $\div$ (square feet of heating surface $\times$ items $10 - \frac{13 + 14}{2}$).

Summarizing the results, when air is present much in excess of ½-inch of mercury pressure there is either a major leak in the packing of the valve or piston rods, or the air pump leaks badly in its valves or around its piston. When the air pressure is satisfactory and the vacuum is still low, a dirty condenser will be indicated by a low heat transfer, which may be recognized from item 15, which is the temperature difference between the vacuum and outgoing circulating water. This (item 15) should not be over 15° in good practice; note that in the table, before cleaning the condenser, this difference was 42.9°F., and after cleaning 12.2°F. The last difference of 24°F. and 29 inches vacuum indicates that too much circulating water was going through the condenser, because, although a high vacuum was obtained, the condensate was cooled too much, incurring a waste of heat (Compare items 12).

TABLE 1

1. Date	May 24	June 17	Winter
2.	Before cleaning	After cleaning	After cleaning
3. Barometer, corrected	29.65″	29.68″	29.32″
4. Vacum by column, corrected	25.67″	27.59″	28.42″
5. Absolute pressure	3.98″	2.09″	0.90″
6. Vacuum (30″ Barometer)	26.02″	27.91″	29.09″
7. Vapor or condensate temperature	120.5°	94.7°	58.0°
8. Vapor pressure (30″ Barometer)	3.50″	1.64″	0.48″
9. Air pressure	0.48″	0.45″	0.42″
10. Exhaust steam temperature	125.0°F.	103.2°	76.5°
11. Corresponding vacuum	26.04	27.88	29.08
12. Items 10–7, circulating water	4.5°F.	8.5°	18.5°
13. In, temperature	73.2°F.	81.5°	43.0°
14. Out, temperature	82.1°F.	91.0°	52.5°
15. Items 10–14	42.9°F.	12.2°	24.0°
16. Heat transfer	87 B.t.u.	237 B.t.u.	145 B.t.u.

And now we come to the question of what is a proper vacuum for a triple expansion crank and fly-wheel type of pumping engine.

Figure 1 shows the results of duty tests made on the same pump, keeping all conditions but the vacuum constant. Note that there

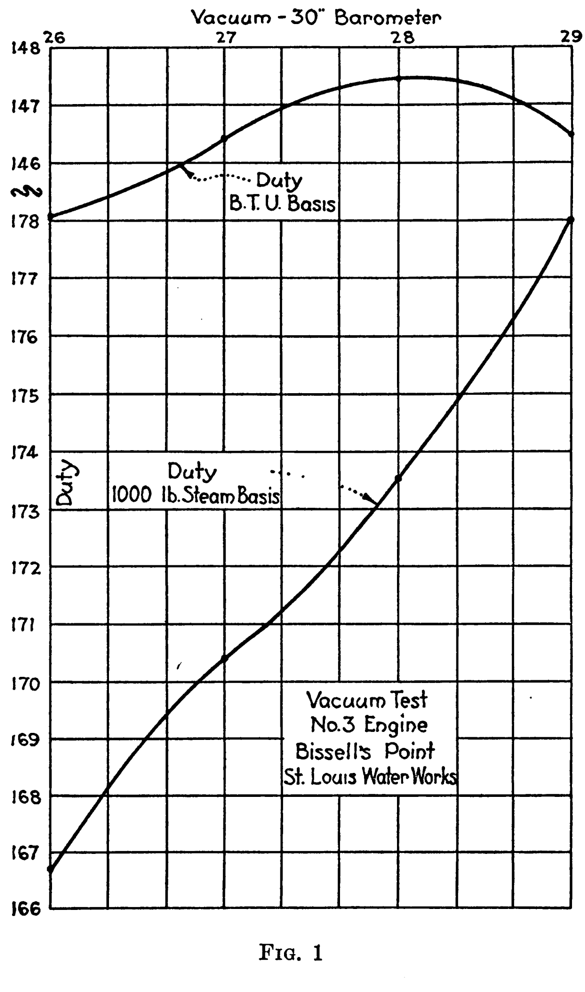

Fig. 1

is but little variation in the duty (B.t.u.) between a 27-inch and a 29-inch vacuum. The duty on the B.t.u. basis is a true measure of the heat input into an engine for a certain output, i.e. the heat input which has to be supplied by the boilers, which is the difference

in heat content between the steam and the condensate or feed water. On the same chart is also plotted the variation of duty on the 1000 pounds of steam basis with vacuum, which shows a rapid increase up to 29-inch vacuum. It shows this increase because it does not take into consideration the heat rejected in the condensate (compare items 6, 7, 12 and 15) and is therefore a misleading index of how economically the pumping engine is operating. From figure 1, it is seen that a 28-inch vacuum is better for operating economically than a 29-inch vacuum, provided an increase in the temperature of the air pump discharge water can be utilized to advantage, and that in the winter months, although it were possible to obtain a higher vacuum due to the cold circulating water, it will be well to throttle the circulating water to the condenser, not cool the condensate

TABLE 2

PRESSURE DUE TO AIR, INCHES OF MERCURY	B. T. U. EXTRACTION	
	Upper half	Lower half
	per cent	*per cent*
2.9	81	19
2.76	72	28
2.07	75	25
1.9	70	30
1.42	70	30
0.48	45	55

excessively, and maintain a lower vacuum, or install a feed water heater in the exhaust pipe, if the circulating water in the condenser can not be controlled.

It was previously mentioned that air was mostly present at the bottom of the condenser. The following table shows the distribution of work between the upper and lower halves of condensers for different quantities of air present.

Consequently when air is removed from a condenser the entire surface of the tubes becomes effective. To show further the presence of air in the bottom, readings taken on the same condenser gave an air pressure at the steam inlet of 0.017 inch and at the vacuum pump suction of 0.64 with an absolute pressure of 1.58 inches. Excess air was then admitted to the condenser so that the absolute pressure increased to 2.2 inches, when the air pressure at

the steam inlet measured 0.008 inch and at the vacuum pump suction 1.265 inches. These values show the effect of air presence to be negligible at the steam inlet of the condenser. As a consequence the temperature of the vacuum taken there is practically a true measure of the vacuum. Referring to table No. 1, note the agreement between items 6 and 11, the latter having been determined from the steam temperatures, item No. 10.